than one molecule of lead peroxide, and the possibility of local action gradually diminishes as the reduction proceeds.

All our other experiments told the same story as far as the absorption of hydrogen is concerned, but there are differences on the other plate. In one or two instances, not half of the theoretical amount of oxygen was absorbed. On searching into the circumstances on which this depended, we were unable to arrive at any other conclusion, than that it was connected with the condition of the surface of the lead plate.

Experiments with a current of about two Ampères showed that a larger quantity of both hydrogen and oxygen was fixed in a given time, but there was a larger proportionate loss, especially in the case of oxygen. Experiments with a current of about half an Ampère, on the contrary, gave a somewhat less rapid action, but a smaller waste of force through the escape of free gas.

A complete study of the results of these experiments would be instructive, but the following comparisons may suffice to illustrate the points just mentioned. The theoretical amount of oxygen required for the red lead used is about 1200 cc., and the table shows the length of time in which 300, 600, and 1000 cc. were fixed by different strengths of current, together with the accompanying loss.

Strength of current.	Amount of oxygen stored.	Time.	Loss of oxygen.
Ampères	c.c.	hours.	c.c.
2	300	1·5	174
1	,,	2	18
½	,,	3·8	15
2	600	4·1	617
1	,,	5·5	249
½	,,	7·6	47
2	1000	13·9	3081
1	,,	12·2	900
½	,,	16·0	400

In some cases we mixed the red lead with a little water, and allowed it to dry. In other experiments we mixed it at once with dilute sulphuric acid, but without any particular practical advantage.

The forming of a good secondary battery is a matter evidently depending upon very nice adjustment of conditions. It is but a few of these that we have carefully studied; nevertheless we feel ourselves in a position to make one or two suggestions in regard to the economic aspects of the question. It is evident that the energy stored up in a cell is determined mainly by the amount of peroxide present. This appears to be obtained with the smallest amount of waste when the current is not too strong; in fact, in our experiments it was obtained when the density of the current was about 6½ Ampères, calculated on the original surface of the lead plates.

There would seem to be no commensurate advantage in continuing the current after the oxygen has ceased to be absorbed pretty freely, because the presence of some unoxidised sulphate of lead, although it increases the resistance, rather impedes than promotes local action.

On the other hand, however, it is necessary that the reduction of the minium on the opposing plate should be complete, for a mixture of lead peroxide and metallic lead would be peculiarly conducive to the production of lead sulphate, and thus increase the resistance; while if any peroxide should remain, it would diminish the electromotive force of the cell.

It would appear probable, therefore, that the most economical arrangement would be obtained by making the red lead to be hydrogenated much smaller in amount than that to be oxidated. On trying the experiment with only half the quantity, we obtained a most satisfactory result as far as the charging was concerned. How far such an arrangement may be really desirable we hope to consider more fully when we treat of the chemistry of the discharge.

J. H. GLADSTONE
March 9 ALFRED TRIBE

THE CHANNEL TUNNEL

THE two schemes for a tunnel beneath the Channel, on the comparative merits of which a Parliamentary Committee will probably take evidence in the course of the year, are based, like those which have preceded them, chiefly on geological considerations. The Weald of Kent and the Bas-Boulonnais, once in all probability geographically continuous, still constitute a single geological area. The chalk of Calais and Sangatte forms the prolongation of that long range which, striking through Dover, Rochester, and Guildford, to near Basingstoke, is known as the North Downs; while that which strikes the coast south of Boulogne, is continued in Beachy Head, and the long range of the South Downs. The North and South Downs curve gently round, so as to meet towards the west, and similarly the Bas-Boulonnais is inclosed by the meeting of the two ranges on the French coast towards the east.

In both these districts the beds of the chalk dip away from the inclosed area, generally at a gentle angle as at Dover, but sometimes steeply as in the Hog's Back. It is clear from this that the beds which rise to the surface in the Weald and in the Bas-Boulonnais are geologically older than the chalk, and must pass under it laterally. The escarpments of the chalk may thus be compared to the fragmentary walls of an oval dome, the top of which has decayed away. The longer axis of this dome extended approximately east and west.

The sequence of beds from the chalk downwards is as follows[1]:—

		English Coast. feet.	Bas-Boulonnais. feet.
Upper	Chalk with flints	350	
	Chalk with few flints	130	
Lower	Compact nodular without flints	90	... 130
	Chalk without flints	50	
	Grey Chalk	200	... 180
Upper Greensand		0–12	... 0–3
Gault		100	... 30–36
Lower Greensand		250	... 12½
Wealden Beds	Weald Clay 350 / Hastings Beds 800	1150	... 100?
Purbeck Beds		400	
Portland Beds		80	Sub-Wealden Boring[2]
Kimmeridge Clay		1070	Sub-Wealden Boring[2]
Coralline Oolite		550	Sub-Wealden Boring[2]
Oxford Clay		60	Sub-Wealden Boring[2]

Of these formations the Chalk and Gault have been proved to run with remarkable persistency over a very large area, changing in thickness slowly and uniformly in ascertained directions. It thus was a matter of the utmost probability that they would be found occupying their proper position relative to the other formations, and of their usual dimensions, in the narrow strip occupied by the sea. All doubts on this point were set at rest by the experimental soundings conducted by Sir J. Hawkshaw, and subsequently in greater detail by the French engineers, MM. Lavalley, Larousse, Potier, and de Lapparent; 7,671 soundings were taken by these gentlemen, and 3,267 specimens of the bottom were brought up, nearly all of which could be identified with certainty as belonging to one or other of the formations named above. A [geo-

[1] The thicknesses of the Chalk on the English coast are taken from the Geol. Survey Memoirs, vol. iv.; those of the Bas-Boulonnais from the French Report of 1877, the thickness of the Lower Chalk being estimated by the position of the lowest beds of flint.

[2] There is some uncertainty as to the thickness of these divisions.

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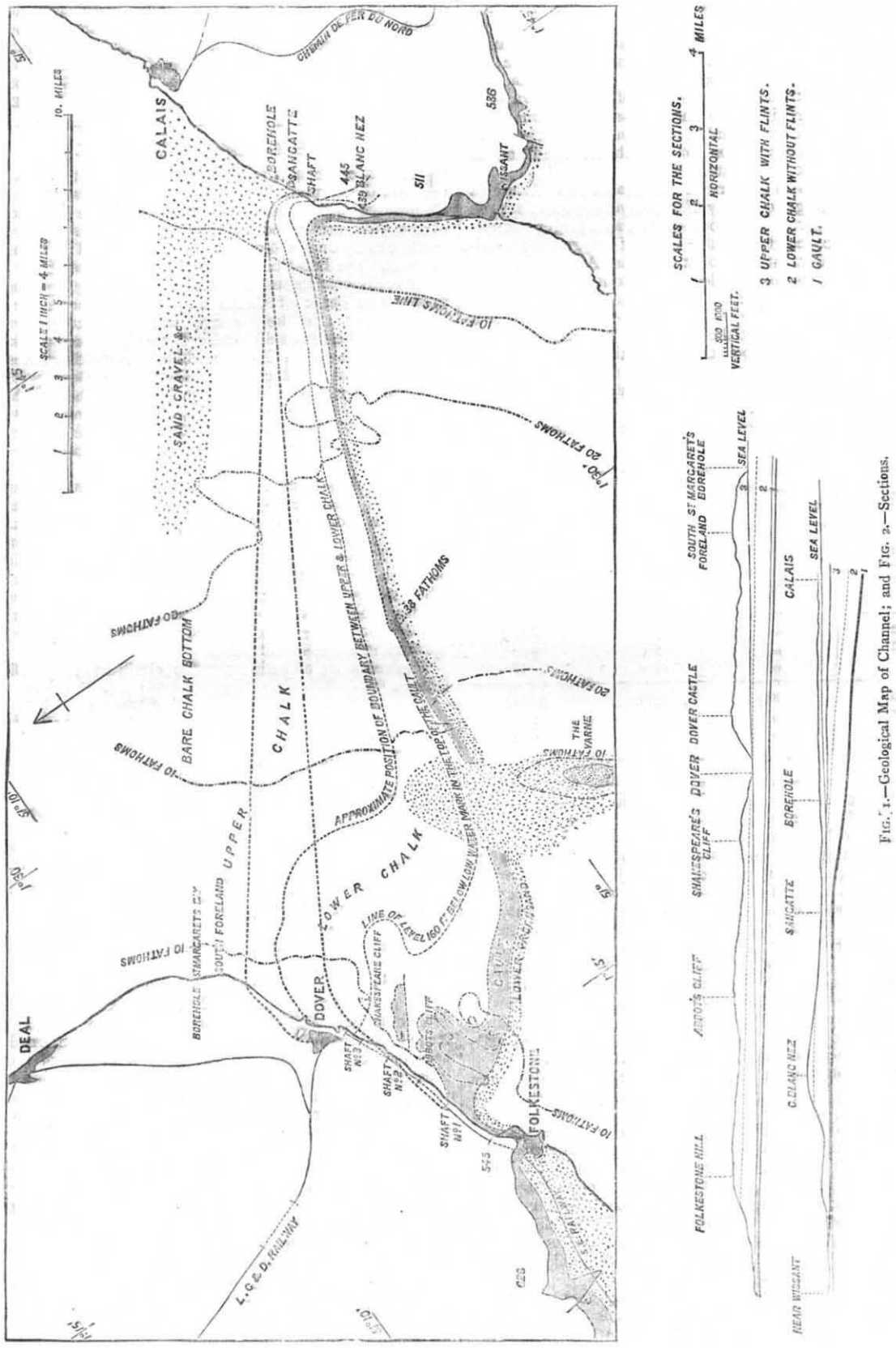


FIG. 1.—Geological Map of Channel; and FIG. 2.—Sections.

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logical chart of the straits was thus made, showing the outcrops of the beds in the Channel from the Gault upwards. On this chart the submarine geology shown on the map (Fig. 1) accompanying this article is founded. The outcrop of the Gault is shown, and an approximate separation of the Lower Chalk from the Upper Chalk. It may be mentioned here that the lowest division of the chalk made by the French geologists, and known as the Craie de Rouen, does not exactly correspond with our Lower Chalk, which includes part of the overlying sub-division, the Craie Moyenne. The series of vertical sections (Fig. 3), which has been constructed to illustrate the remarkable persistence of the subdivisions of the Chalk, partly shows also the difference between the English and French classifications. The base of the Gault has been selected as an artificial datum line in plotting these sections.

The Lower Greensand on the other hand is probably represented only in its upper beds in the Boulonnais, while the Wealden beds are so changed and attenuated that the subdivisions made in England are unrecognisable in France. The Kimmeridge Clay reappears, but much reduced in thickness, as indeed is the case with all the lower secondary formations. For all these earlier beds rest upon an uneven rock-floor, carved out of a vast mass of contorted palæozoic rocks; and a ridge forming a prominent feature in this old surface existed in what is now the north part of the Bas-Boulonnais, and perhaps stood above water through all the earlier part of the Secondary Period, until it was finally submerged beneath the water of the Gault sea. The filling up of the inequalities in the old surface probably contributed to the more even distribution of the Gault and Chalk. The only point at which the Palæozoic Rocks now appear at the surface in the district is in the north-east corner of the Bas-Boulonnais, but they have been reached in boreholes in London, Calais, and Guines as shown in the sections.

It was proposed by Prof. Prestwich to carry the tunnel through these Palæozoic rocks on the grounds that they are of great dimensions, and protected by overlying impermeable strata. But their great depth has prevented much attention being paid to the scheme; at Calais they are at 1160 feet below the surface, in London 1064, and near Battle in Sussex they have not been reached at 1900 feet. It has also been suggested that a tunnel starting in the Weald Clay on the English might be carried through into the Kimmeridge Clay on the French side without encountering the intervening Portland beds, it being supposed that these watery strata might thin out and leave the two clays in contact. But at the present time the inquiry has narrowed itself to the Chalk, the lower part of which is not only most suitable for tunnelling, but has the advantage of occupying the narrowest part of the Channel.

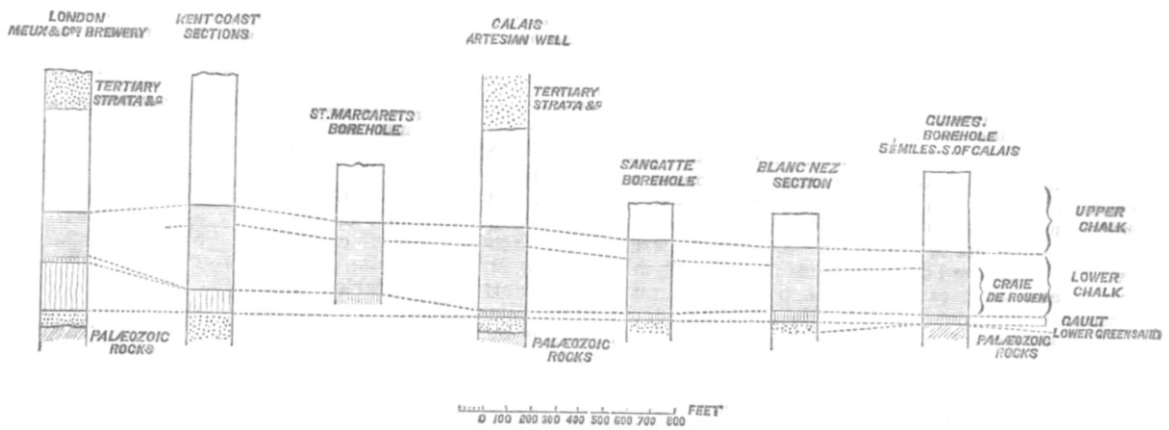


FIG. 3.—Sections showing the Persistence of the Lower Chalk.

The two schemes which are offered for tunnelling through the Chalk may be briefly stated as follows:—

1. The Channel Tunnel Company, with which Sir John Hawkshaw is connected, propose a tunnel starting from Biggin Street, Dover, with a gradient of 1 in 80, passing under the north spur of Dover Castle Hill, and thence continuing to a point on the shore known as the Fan Hole at a distance of 2 miles, 4 furlongs, 2·50 chains from Biggin Street, and at a depth of 115 feet below high water ordinary spring tides. From this point it will run across the straits to join the French tunnel, which commences near Sangatte, and as Sir J. Hawkshaw has always advocated a straight line of tunnel, we presume that such will be the case here.

2. The Submarine Continental Railway Company, with which Sir E. Watkin is associated, propose a tunnel connected with the South-Eastern Railway, about two furlongs west of Folkestone entrance of the Abbotscliff Tunnel by a tunnel descending at a gradient of 1 in 52 to the bottom of the No. 2 Shaft, near the west end of the Shakspeare Tunnel, at a depth of 126 feet below high water ordinary spring tides. From this point the tunnel will continue for about a mile towards the head of the pier in a direction slightly diverging from the shore, and finally curving round, will fall into the line of the French tunnel near Sangatte. In Sir John Hawkshaw's scheme the tunnel will start on the English coast in the lower part of the Upper Chalk, but will rapidly reach the Lower Chalk, and probably remain in it throughout. In that proposed by Sir Edward Watkin, the inclined plane leading to the tunnel, and the tunnel itself, will be driven from end to end in the same bed of grey chalk which constitutes the lower part of the subdivision of the Lower Chalk.

So far as our information goes at present it seems that the most serious obstacle will be water, and it is therefore on their relative liability to flooding that the proposed tunnels must be judged. In the Belgian Coal-field, where Coal-measures are worked under secondary strata full of water, it is found that those works are dry which "follow the vein," while those which cut across the strata are invaded by water. For the Coal-measures rise up to and end off in succession against the base of the secondary strata (which rest unconformably upon them), so that every bed, whether porous or not, is in contact with the water. It is clear then that a level, which cut across the strata, would run a far greater chance of intersecting a water-bearing rock than one which always followed the same bed. Now a precisely analogous position is held by the rocks which form the floor of the Channel relatively to the water which occupies it. The strata rising to the south-west crop out in succession in the sea-bottom, and, being for the most part bared by the scour of the tide, must be fully saturated with water. In an impermeable bed this would

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make little or no difference to mining operations, but to encounter a porous bed such as the Lower Greensand under such circumstances would be to tap a reservoir as inexhaustible as the sea itself. Fortunately an excellent water-tight barrier between this quicksand and the Chalk above is provided in the Gault. The Upper Greensand, which lies next above the Gault, is generally thin, but occasionally expands rapidly from almost nothing to six or eight feet, and, though as rapidly dwindling down again, it might under such circumstances conduct a large amount of water. The French engineers have tested it at intervals by borings in the drift-ways, and have observed that water rises from it in most cases. But it is generally too insignificant to prove dangerous.

That it would be advisable to choose the most favourable bed, and to follow it for the whole distance, if this were possible, is not to be denied. But a study of the map shows that to do this it would be necessary either to make at least two considerable curves in the tunnel, or else to make it rise and fall with the beds, which would probably be prejudicial to drainage and ventilation. For the form of the outcrop of the Gault shows that close to both shores the strata are bent upwards in the form known to geologists as anticlinals. The outcrops incline to the north-east in such a way that the Gault occupies a position in the line of prolongation of the Lower Chalk, indicating clearly that it is arched upwards at these points, and therefore intersects the sea-bottom further to the north-east than it would if it formed a plane surface. The anticlinal which passes near Sangatte is partly shown in one of the longitudinal sections accompanying the map, but would be more manifest in a section running in the direction of the proposed tunnel. Again, about midway between Dover and Folkestone an isolated patch of Gault appears through the Lower Chalk. This patch is believed to be bounded on the south-west by a fault, not necessarily of large amount, and probably dying out to a mere gentle roll in the strata seaward. To make the lie of the beds more intelligible, the French engineers calculated the position of three horizontal lines following the top of the Gault at a depth of 50, 100, and 150 mètres respectively below low-water mark, and one of these has been placed upon the map accompanying this article. The inequalities of the surface of the Gault are shown by this line in the same way that the inequalities of the ground are shown by a contour line.

The thickness of the Lower Chalk is such that in spite of these undulations in the beds a tunnel originally planned to run near the middle of the subdivision, might continue a straight course with an unchanged gradient, and still remain with its limits. But if running near the top a synclinal or downward bend would bring the Upper Chalk into the line of the tunnel, while if running near the bottom, an anticlinal or upward bend would bring in the Gault. It is obvious then that a tunnel traversing the lower portion of the Chalk, on encountering an anticlinal, would be compelled to bend towards the north-east in order to preserve a constant gradient, and at the same time avoid touching the Gault. It is believed that the route advocated by Sir E. Watkin is so planned as to round the two anticlinals described above, as occurring on either side of the Channel. It remains to be seen whether the form of the beds will admit of its being carried in a straight line, and at the same time in the bottom beds of the Chalk, for the remainder of the distance. In the route proposed by Sir John Hawkshaw, the effect of an anticlinal would be to bring up the lower beds of the Chalk into the line of tunnel, and would therefore not be unfavourable; a synclinal might probably bring down the Upper Chalk with flints, which, as will be shown subsequently, is not desirable.

A similar source of uncertainty exists in the possible occurrence of faults, that is, lines of fracture in the strata, on one side or other of which they have been vertically shifted. The Gault in mid-channel being presumably about 50 or 60 feet thick, a fault of this amount might bring the base of the Chalk and the top of the Lower Greensand face to face. The submarine mapping, however, if it can be trusted, shows that it is very improbable that there is a fault of this amount in the channel. A fault would displace all the beds of the Chalk in succession equally or nearly so, but its effect would be less perceptible higher in the system where chalk would be thrown against chalk, than at the base where chalk might be thrown against the Gault or Greensand. It remains to be considered which of the subdivisions of the Chalk is the most suitable for operations, and whether sufficient difference exists between the various beds to make the experience of the Belgian miners directly applicable to the Channel Tunnel.

The lower part of the Grey Chalk, the lowest subdivision of the Chalk as shown in the table, is universally stated to be very impermeable. Prof. Prestwich, in the "Water-bearing Strata of London," p. 63, states: "The lower beds of the Chalk are generally so argillaceous that the rock often puts on the character of an argillaceous clay, which on exposure to air and water softens to a tenacious mud. When first exposed its colour is bluish grey, but it becomes white or nearly so as it dries. . . . They everywhere form a generally impermeable mass of strata, between the Upper and the Middle Chalk above, and the Upper Greensand below." The Grey Chalk or Craie de Rouen, about 60 to 70 feet from its base, throws out springs. The powerful spring of Lydden Spout, for example, is thrown out at about this horizon, where a small fault, probably the continuation of that inferred by the French in the Channel, slightly disturbs the beds. Springs are observable also on the French coast between Sangatte and Wissant at this horizon. The compact nodular Chalk is very impermeable; Prof. Ed. Hébert (*Bull.* Soc. Geol. de France, Ser. 3, t. iv. p. 60) states that the highest part of the Chalk without flints is preferable as regards impermeability to the Craie de Rouen itself; it has never yielded water in any of the Artesian wells near Paris, and is always clayey when met with at great depths. The various sub-divisions which constitute the Lower Chalk form the undercliff from about two miles east of Folkestone, as far as the South Eastern Railway Terminus. Dipping gently down to the north-east, they were reached at 249 feet below sea-level at St. Margaret's Bay in Sir John Hawkshaw's borehole.[1]

The divisions of the Upper Chalk, namely the Chalk with flints, and the Chalk with few flints, differ chiefly in the mode of occurrence of the flints; in the former they occur in layers, in the latter they are scattered and far between. This difference is important, for the layers of flint often give rise to channels by which water circulates in the chalk. The chalk with a few flints occupies the beach from Dover Castle eastwards, until it is succeeded in due course by the Chalk with layers of flints. The former throws out a few springs, the latter a large number, and it is generally agreed that the Upper Chalk, and particularly the chalk with layers of flints, is the most heavily watered part of the formation.

The circulation of water in chalk takes place principally by means of fissures, the unfissured rock being of such close texture as to be practically impermeable. Prof. Prestwich, for example, has estimated the relative permeability of chalk and coarse sand to be as 1 to 6400. But when the fissures are numerous, and the rock contains layers of flints, the water is enabled to circulate with great freedom. The Upper Chalk is more liable to fissures than the argillaceous lower division, and for this reason excels it as a water-bearing formation.

[1] See sections (Fig. 2) accompanying the map. These have been copied with slight modifications from a paper by Mr. Topley in the *Quarterly Journal of Science* for April, 1872.

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Now the principal difference between the two proposed routes consists in the fact that Sir E. Watkins' tunnel starts in the impermeable portion of the chalk with a view to following it all across, while Sir J. Hawkshaw's tunnel starts in the lower part of the Upper Chalk, and descends subsequently into the Lower Chalk, probably into that portion of it which, as stated by Prof. Hébert, is less permeable than the Craie de Rouen itself. The possible difficulties that may arise from following the base of the chalk too closely have already been pointed out. It remains to be seen how far the fact of starting in the Upper Chalk is prejudicial.

In spite of the vast quantities of water that have been obtained from the Chalk,[1] there are many instances of wells and deep bore-holes having failed to obtain a supply. A well at Dover Castle, 363 feet deep, or 1½ feet below low-water mark, and with a tunnel 160 feet long at the bottom, can be pumped dry in three hours by a 30 horse-power engine (Statement by the Committee of the Channel Tunnel Company). Deep bore-holes, such as those at Harwich, Hampstead, Calais, and Grenelle, though traversing the whole Chalk system, have been unsuccessful, and many other instances might be quoted to show how uncertain is the amount obtainable by this means. The plan adopted at Ramsgate, and afterwards at Brighton in consequence of the supply from wells being inadequate, throws much light on the circulation of water in chalk. Mr. Easton (Brit. Assoc. Rep. 1872) states that a well was sunk, and the direction of the fissures having been ascertained, a tunnel was driven at right angles to them, so as to intercept the greatest number in the shortest distance. Such a tunnel driven under Goldstone Bottom traversed 160 feet of solid chalk without finding water. It then encountered an enormous fissure yielding 1000 gallons per minute. This was followed at about the same interval by another of about equal capacity. At the Lewes Road the fissures were about 30 feet apart and yielded about 100 to 150 gallons per minute. At Ramsgate the supply was obtained by driving parallel to the shore at about low water-mark. The fissures were observed by Mr. Easton to run at about right angles to the coast line, so that it is clear that a tunnel might have been driven in this direction for a long distance without cutting a fissure. That a tunnel can be driven even in the most favourable situation for tapping water has been proved by Sir J. Hawkshaw, who, in the discussion which followed Prof. Prestwich's paper (*Proc.* Inst. C.E. xxvii.), stated that "he was now completing at Brighton a tunnel of 5¼ miles in length, wholly through the Upper Chalk and below the level and within a short distance of the sea. There was a large amount of water from land-springs. The quantity of water pumped varied from 8,600 to 10,000 gallons per minute. This was a large quantity, but it did not prevent the tunnel from proceeding." The same length of tunnelling taken seawards at a greater depth might have carried the works clear of these difficulties, for there is reason to believe the fissures are most numerous and widest above or near the sea-level.

These fissures, originally mere cracks due to unequal contraction or expansion in the mass of the chalk, owe their enlargement to the passage of water through them, acting partly mechanically by erosion, partly chemically by dissolving the carbonate of lime. Although they are met with at considerable depths, as for instance in the borehole at St. Margaret's Bay, where a cavity of 3 feet depth, and filled with salt water, was found at 209 feet, yet they are most numerous where the circulation is most active, namely, about the water-level. It is at this level, as well as above the outcrop of an impermeable bed, that the largest inland springs occur, and it is at the sea-level that the largest quantity of water escapes from the cliffs on the coast. Beneath the waters of the Channel there may be but little movement in the rock-water, and what fissures or faults may exist, as well as the channels following the layers of flints are probably more or less choked from long disuse. While therefore it is not likely that the approaches to a tunnel can be made under the coast in the Upper Chalk without meeting with much water, it does not necessarily follow that the quantity will be so great as to be utterly unmanageable. That it is expected to be considerable may be inferred from a statement by Sir John Hawkshaw in the discussion before referred to, that the engines used in the Brighton tunnel "were, in the aggregate, of 150 horse-power, but provision had been made in estimating the possible cost of the Channel tunnel, for engines of about 2000 horse-power."

Finally, it may be stated that the works, so far as they have gone, have confirmed the expectations formed as to the character of the rocks. The shaft at the west end of Abbot's Cliff Tunnel has been taken to a depth of 160 feet, and a drift-way carried in the Lower Chalk for 1100 yards in the line of the tunnel proposed by Sir E. Watkin, without meeting water. On the French side two shafts have been sunk near Sangatte to a depth of 280 feet, entering the Craie de Rouen at the sea-level, and a tunnel has been driven in a north-easterly direction at about 170 feet below the sea-level, with trial holes at intervals to the Gault, which is about 7 feet below. A little water issues from these, but the total amount that has to be pumped does not exceed 80 gallons a minute. Up to the present time no further trials have been made in the Upper Chalk at the spot selected for the works by Sir J. Hawkshaw.

A. STRAHAN

[1] In the discussion on a paper by Mr. Lucas (*Proc.* Inst. C.E. xlvii.) Mr. Homersham stated that 11,000,000 to 12,000,000 gallons daily had been taken from the chalk in an area of 150 square miles about London for some years.

SIR CHARLES WYVILLE THOMSON

THE news of the death of Sir Wyville Thomson, on the 10th instant, from the effects of paralysis, will be received with general regret. Sir Wyville was only in the 53rd year of his age. On the return of the *Challenger*, we gave so full an account of Sir Wyville's life and work (vol. xiv. p. 85) that we need not go over the same ground again.

Charles Wyville Thomson was a descendant of an old Scottish family which had long resided at Bonsyde, Linlithgow. His father was a surgeon in the service of the East India Company. Born at the family residence on March 5, 1830, Wyville Thomson became, at the age of twenty-one, a lecturer on Botany in King's College, Aberdeen. In 1853 he became Professor of Natural History in Queen's College, Cork; but he had only been there a year when he succeeded to the Chair of Mineralogy and Geology in Queen's College, Belfast. In the expeditions of the *Lightning* and *Porcupine* in 1868 and 1869 he took part, and the discoveries then made in regard to the fauna of the Atlantic Ocean he subsequently gave to the world in a work entitled "The Depths of the Sea." On the resignation of Prof. Allman, Prof. Thomson was elected Regius Professor of Natural History in the University of Edinburgh, where his abilities as a lecturer raised the class of zoology to a position of great importance, the numbers attending it being probably unequalled. Of the famous expedition in the *Challenger*, Prof. Thomson was appointed the scientific chief. Leaving England in 1872, the exploring party was absent for three and a half years, during which time 68,890 miles were traversed, and systematic observations made at 362 stations in the open sea, notes being also made on land and in shallow water, as opportunity offered. The natural history and other collections obtained were very extensive. These large collections were from time to time sent home to Edinburgh, where the head office of the expedition was subsequently established; and it was only appropriate

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